

**National Cooperative Highway Research Program  
Projects in the Fiscal Year 2004 Program**

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## SUMMARY OF APPROVED RESEARCH PROJECTS

### ◆ Project 01-44

#### *Quiet Pavement Pilot Project Study*

Research Field: Design  
Source: California  
Allocation: \$250,000  
NCHRP Staff: Amir N. Hanna

The public is demanding that highway traffic noise be mitigated. At a cost of more than \$1,300,000 per mile, sound walls are the only approved FHWA solution for addressing highway noise impacts. Caltrans has built more than 600 miles of sound walls at an average annual cost of \$60 million. Other states have incurred significant costs mitigating highway traffic noise. The only component of traffic-related noise under the control of DOTs is the acoustical property of the pavement. In response to the public outcry for quieter pavement, Caltrans has developed a very accurate, inexpensive, and repeatable methodology for measuring tire/pavement noise using sound intensity. Using this approach, pavement noise properties can quickly be assessed, equitably compared and ranked. This information can be used to help design quieter pavements.

Quiet pavement offers a less-expensive means for noise mitigation. However, there are currently no adequate scientifically based criteria for designing quiet pavements. An important early step in developing adequate quiet pavement design criteria is to perform a nationwide survey of both asphalt concrete (AC) and portland cement concrete (PCC) pavements, using an innovative sound measurement technology, to develop a nationwide index that ranks various pavement acoustical properties from the quietest to the loudest.

The objective of the research is to perform a quick nationwide survey using an innovative sound measurement technology and develop a nationwide index of the acoustical properties of AC and PCC pavements from quietest to loudest. From the data developed by the survey, characteristics that can be used to help develop quiet pavement design criteria and guide traffic-noise-related engineering and management decisions will be identified.

Note: The AASHTO Standing Committee on Research approved this problem statement in lieu of the original Problem No. 2005-D-34, which called for a major research effort estimated at \$2.5 million.
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◆ **Project 03-80**

***Work Zone Enforcement Effectiveness***

Research Field: Traffic  
Source: California  
Allocation: \$500,000  
NCHRP Staff: B. Ray Derr

Work zone enforcement is becoming almost mandatory on many projects throughout the country. The safety benefits of added enforcement are unquestioned. However, the benefits of work zone enforcement may not be proportional to the cost. The projects selected for work zone enforcement and enforcement methods and procedures (e.g., officer placement, work routine) may not be optimum, given the millions of dollars being spent on an annual basis.

While work zone enforcement is being accomplished in major urban, high-traffic situations, various agencies at the state and federal level have begun encouraging project engineers to include this strategy as a standard practice. The primary objective is to minimize traveler delays without compromising public or worker safety or the quality of the work being performed.

The objectives of this project are to (1) evaluate various enforcement methods and procedures (e.g., media campaigns and fines) in current work zones to assess the impact on safety and mobility; (2) determine the optimum procedures for selecting projects for work zone enforcement; and (3) develop model enforcement methods and procedures.

◆ **Project 03-81**

***Integrated Control for Improved Operation of Freeways and Surface Streets in Urban Corridors***

Research Field: Traffic  
Source: Washington  
Allocation: \$500,000  
NCHRP Staff: B. Ray Derr

Conditions on any roadway can, and often do, affect the operation of neighboring roadways. Typically, whenever congestion occurs on one roadway, some of the travelers respond by shifting to another route, selecting a different type of roadway (freeway versus surface street), or adjusting their trip to another time of day. Consequently, when congestion occurs on a roadway, the adjoining roadways in the corridor are also typically impacted.

Public agencies have the potential to improve safety and the flow of traffic when events disrupt travel within transportation corridors. Integrating the control of freeway and traffic signal control systems, within the same urban corridor, allows for the implementation or modification of the operational strategies and traffic control plans in response to changing roadway conditions. Integrated control provides the capability for agencies to proactively manage and control traffic to improve travel on a specific roadway, at a series of intersections controlled by traffic signals, at interchange ramp terminals, or within an urban corridor where travel occurs on alternative freeways and surface streets. Traditionally, the emphasis of the traffic management activities of most agencies has been on limited portions of the freeway facilities or on surface streets controlled by traffic signals located within urban corridors.

The objectives of this project are to research methods of integrating the control of freeway and traffic signal control systems and to develop a technical reference that provides guidance and recommended practices on integrating control of these systems. The primary audience of this document is the team of individuals who are responsible for managing and operating traffic control systems that control traffic on these roadway facilities in urban corridors. The secondary audience is the team of individuals who support the primary audience, those involved in or responsible for managing, planning, designing, and operating these systems. The document is not intended to serve as a detailed design guide.

The project should use a thorough literature review and synthesis to identify best practices and gaps in previous research. The most important gaps should then be addressed through new research. These efforts should culminate in a document that considers methods and types of integrated control; operating concepts and scenarios; equipment, software, communication, surveillance, database, and data needs; system and device integration to share data and control; and traffic control algorithms and control plans. Also important to consider are methodology; simulation tools; process; analysis techniques; and factors important to the development or evaluation of traffic control capabilities, operational strategies, and signal timing plans. The document should describe how the research results can be implemented by transportation agencies including training and staff development activities to ensure that the direction, guidance, and recommended practices produced in this effort reach the intended public agencies and transportation practitioners.

## ◆ Project 05-19

### *Development of Warrants for Roadway Lighting Based on an Evaluation of Safety Benefits*

Research Field: Traffic  
Source: Federal Highway Administration  
Allocation: \$800,000  
NCHRP Staff: Christopher J. Hedges

*NCHRP Report 152: Warrants for Highway Lighting*, issued in 1974, provided a “total design process” for roadway lighting to meet the visual information needs of drivers based on tasks involving position, situation, and navigation. The information needs were classified based on geometric, operational, and environmental conditions and accident history. In turn, these conditions were the parameters used to develop classification schemes. Four classification schemes were developed as the basis for evaluating lighting needs and minimum warranting conditions. The classifications are for non-controlled-access facilities, intersections, controlled-access facilities (freeways), and interchanges. Unfortunately, few states have used *NCHRP Report 152* for evaluating lighting requirements due to the complexity of the classification process and the need to have accident history prior to conducting an evaluation for a given roadway. As an example, existing warrants are not appropriate for determining the requirement for lighting on new facilities. Any system that purports to establish the requirement for roadway lighting must have the ability to analyze existing, rehabilitated, and new facilities equally.

States are under pressure to justify roadway lighting in the face of political pressure to reduce power consumption and also light trespass. Without a reevaluation of the benefits of roadway lighting across the myriad conditions and roadway classifications, it is difficult to produce a readily understandable and defensible benefit/cost analysis for key decision makers. A readily understandable, yet comprehensive, evaluation system for developing benefit/cost analyses of fixed roadway lighting is critical to ensuring that this important aspect of safety is adequately considered and to allowing decisions to be made that result in the greatest benefit to society. There is an urgent need to update existing warranting systems to reflect the improvements in roadway geometry (offset by significant increases in congestion), incorporate improved vehicle dynamics, and examine the significant advances in lighting designs and understanding of driver needs across the full range of roadway classifications and facility status (existing, rehabilitation, new construction). The objective of this study is to develop guidance on the selection of appropriate roadway lighting for a given facility.

The work plan should include tasks such as the following:

1. Conduct a literature review on the development of the present system of fixed roadway lighting warrants and any legislation defining roadway lighting requirements.
2. Conduct a literature review of research on the safety implications of roadway lighting.
3. Develop an analytical tool for evaluation of the potential benefits of roadway lighting across roadway classifications. This tool should result in a weighting scheme for roadway lighting that permits prioritization of lighting projects across these different roadway classifications. As part of the analytical process (and in order to properly weigh the cost of a lighting system for a given roadway classification), this tool should outline the basic design criteria for the lighting system.
4. Develop guidelines to assist users in determining the benefit-to-cost ratio of fixed roadway lighting.

◆ **Project 06-17**

***Baseline Winter Performance Standards***

Research Field: Maintenance  
Source: AASHTO Highway Subcommittee on Maintenance  
Allocation: \$150,000  
NCHRP Staff: Amir N. Hanna

Achieving winter maintenance performance goals is becoming increasingly important, especially in these times of tight budgets, outsourcing, and meeting customer expectations. Following the winter scan tour to Japan in 2002, members of the Winter Maintenance Technical Support Program (WMTSP) of the AASHTO Highway Subcommittee on Maintenance, Snow and Ice Task Force determined that efforts need to be directed to documenting and monitoring performance standards for winter maintenance operations. A wide variety of standards and techniques are being applied both in the United States and abroad with varying degrees of success. These winter performance standards, including their development, implementation, and measurement, need to be researched and documented.

The objective of this project is to do a synthesis of current practices in the area of winter maintenance performance standards both in the United States and abroad to establish a baseline. As time goes on, WMTSP can, through monitoring, determine what advancements are taking place, so that ultimately best practices can be established and made part of the “AASHTO Guide on Snow and Ice Control.”

The synthesis will identify the state of the art of winter maintenance performance standard practices for both in-house and outsourced activities, including development of policies, implementation, and measurement methods.

It is essential that understandable winter maintenance performance standards be developed. These standards can guide winter maintenance operations to achieve desired customer and agency outcomes. Clearly defined standards will assist agencies in developing strategies to efficiently and effectively manage both human and material assets during winter maintenance operations. More uniformity in winter maintenance can improve mobility and safety.



## ◆ Project 07-16

### *Update the AASHTO Guidelines for Traffic Data Programs*

Research Field: Traffic  
Source: Ohio  
Allocation: \$350,000  
NCHRP Staff: Ronald D. McCready

Data on traffic volumes and vehicle classifications, weights, speeds, and lengths are key elements in many aspects of (1) transportation system planning; (2) apportionment of Federal-aid; (3) freight planning; (4) urban and statewide modeling; (5) pavement and bridge design and management; and (6) safety, economic, and environmental analyses. They are also integral to the information we share with travelers and to the data used in calculating performance measures on congestion and travel time, reliability, and predictability. The last update of the *AASHTO Guidelines for Traffic Data Programs* was published in 1992. Since that time there have been significant changes in

- The technologies and tools available for collecting, managing and reporting data from traditional state traffic data programs, ITS traffic monitoring, and MPO and other local agency monitoring programs.
- The acceptance and validation of methodologies for archiving traffic data, factoring short duration counts for seasonal adjustments, and imputing missing data.
- The uses of traffic data to support the new AASHTO pavement design guidelines; apportionment formulae for Federal-aid funding; development of performance measures for indicators such as travel time predictability and reliability and freight, security, and safety planning.
- Application of data for GIS, Internet availability, and other electronic data sharing tools.

Updated guidelines will provide assistance to the many transportation agencies that rely on traffic data to monitor, manage, and operate highway systems; forecast improvement needs; and determine priorities for investment. In addition, updated guidelines will provide help in meeting the federal requirement that every state transportation agency have a traffic monitoring system in place in accordance with requirements spelled out in 23 CFR 500.201 through 500.204.

The objective of this research is to update the guidelines for traffic data programs for state departments of transportation; review the information and recommendations included in current *AASHTO Guidelines for Traffic Data Programs*, particularly those recommendations related to data structure, definitions, imputation, retention, reporting, sample adequacy, and the editing of traffic data; and recommend improvements and updated guidance for consideration by the state departments of transportation for updating the *AASHTO Guidelines for Traffic Data Programs*.

Accomplishment of the project objective will require at least the following tasks:

- Task 1: Survey federal, state, city, and MPO traffic data collectors and users to determine how equipment, applications, methods, needs, and uses have changed since the last update of the guidelines and identify priority areas for updating.
- Task 2: Review the last published *AASHTO Guidelines for Traffic Data Programs*, identify areas that require updating, determine priorities, and refine the scope of the work program based on the priorities identified in Task 1.
- Task 3: Update information, guidelines, recommendations, and standards to reflect changes and innovations in the following areas:
- Traffic data monitoring needs and uses, including the use of traffic data in supporting AASHTO pavement design guidelines; apportionment formulae for Federal-aid funding; performance measures related to travel times, reliability, and predictability; and freight, security, and safety planning.

- Traffic data program structure, including the minimum requirements, components, or elements necessary to implement and maintain an ideal traffic monitoring program.
- Traffic data definitions, including synchronization with commonly used traffic data definitions and federal/national traffic data dictionaries.
- Traffic data field equipment and procedures, including the methods for determining the number and location of traffic samples or counts, site installation/maintenance procedures and equipment maintenance, and testing and calibration procedures.
- Traffic data editing methods and procedures, including statistical methods for factoring short duration counts; aggregating data into annual estimates of average daily traffic; integrating vehicle classification, weigh in motion, ITS, and other possible sources of traffic data and/or data from other roadway sensors (e.g., weather); and guidance on data imputing methodology and its proper use to estimate missing values.
- Traffic data retention and reporting, including a new section that discusses data storage, management, archival methods for data from both traditional sensors and ITS traffic data collection sites, and the value of and need for web reporting tools.
- Traffic data quality control and assurance, including best practices and measures for ensuring ongoing currency, reliability, and accuracy in traffic monitoring data and programs.

Task 4: Prepare a draft comprehensive and concise guidebook for traffic data practitioners. Coordinate review and evaluation by NCHRP, AASHTO, and transportation agencies and incorporate comments and input into the final report.

Task 5: The contractor will be expected to deliver a final report of revised AASHTO guidelines for traffic data programs. In addition, the contractor will be expected to provide flowchart(s) showing all of the steps for developing, implementing, and maintaining an ideal traffic monitoring program with examples.

## ◆ Project 08-51

### *Defensible Internal Capture Rates for Multi-Use Trip Generation*

Research Field: Transportation Planning  
Source: Virginia  
Allocation: \$250,000  
NCHRP Staff: Martine A. Micozzi

As development pressures place increasing demands on the transportation system, developers, community leaders, land use planners, and transportation agency administrators need techniques to enable them to reliably predict the number of net vehicle trips that will be generated by new or infill land development.

For site impact analysis purposes, an internal capture rate that is set too low may unfairly penalize developers by making them pay more than their fair share of costs for transportation mitigation measures; conversely, an internal capture rate that is set too high may unfairly place this burden on the public, rather than on the private sector. Given the politically contentious issue of the internal capture rate used for a given situation, professional guidance based on empirical observations can help make determination of the burdens placed on developers a more transparent and open process.

For zoning policy purposes, such as encouragement or ambivalence regarding mixing land uses, empirical data are needed. Currently, as “so little information is available about internal capture rates that traffic impact studies for mixed-use developments become little more than exercises in speculation” (Ewing et al., in *Transportation Research Record 1780*), this study aims to provide the empirical data necessary.

There may be some forms of multi-use development where planners have no recourse but to collect local data. Alternatively, there may be other forms of multi-use development where national data, if taken from a sufficiently large sample, can yield reliable internal capture rates.

When conducting a site impact analysis, the Institute of Transportation Engineers’ (ITE’s) Trip Generation provides vehicle trip generation rates for different residential, commercial, and industrial developments. Because ITE’s given rates presume “single-use, free-standing sites,” the potential exists for multi-use sites to exhibit fewer vehicle trips than would be calculated using ITE rates; this is due to some trips made within a multi-use development being done on foot. For example, suppose that procedures in Trip Generation are used to find that a fast food restaurant with a drive-in window (ITE Land Use Code 834) and a video rental store (ITE Land Use Code 896) each generate 200 and 100 vehicle trip ends during the peak hour on a weekday, respectively. If these two developments are being placed in proximity to each other, then it may be appropriate to recognize that the total trips for that period will be less than 300. ITE recognizes this aspect and offers guidance for reducing these trips based on various internal capture rates.

The problem, however, is that ITE cautions users that they should “collect additional data if possible, use good professional judgment and exercise caution in applying the data presented herein because of the limited sample size and scope.” Accordingly, when reviewing potential transportation impacts of proposed developments, local and state transportation planners lack a comprehensive, credible data set that can be used to confirm or deny that proposed internal capture rates are indeed sound. Thus, there is a need for clear guidance on appropriate internal capture rates for various combinations of mixed-use development.

This research should accomplish the following objectives: (1) synthesize the existing literature on internal capture rates, including rates that are not formally published but used in practice in state, municipal, and consulting organizations; (2) identify types or categories of mixed-use development for which internal capture rates are needed (these categories may be determined by gaps in the literature and interviews from planning professionals regarding the types of mixed-use development being encountered in practice); (3) collect additional field data that will provide internal capture rates for the various categories of multi-use development cited in the bullet above; (4) describe the extent to which average internal capture rates can be used in lieu of collecting field data when new developments are proposed; and (5) summarize findings in a handbook that can be used by practitioners in a timely manner.

The urgency and payoff potential are medium to high because even if this research cannot eliminate the need for additional field data collection entirely, it can assist planners with deciding when field data must be collected.

Provided the study approach is sound and the sample sufficiently large, better guidance on internal capture rates can be incorporated relatively easily into existing site impact analysis methods, creating a great potential for implementation.

◆ **Project 08-52**

***Rural Community Growth and Sustainability Solutions to Transportation Problems***

Research Field: Transportation Planning  
Source: California  
Allocation: \$100,000  
NCHRP Staff: Martine A. Micozzi

Rural communities, chronically beset with transportation problems, are in need of strategic solutions in addition to the typical financial ones. Abundant research exists on the relationship between smart growth and transportation in urban and metropolitan areas, but there is a dearth of corresponding research for rural communities. The research question will explore the degree to which smart growth and sustainable community principles provide solutions to rural transportation problems.

Rural jurisdictions have unique sets of problems, not the least of which is transportation. Without transportation solutions, supplying rural populations with their basic needs and enabling the long-esteemed rural quality of life will become more difficult to sustain. Because this research addresses transportation solutions, its potential for deployment and technology transfer are significant.

This research will identify and propose smart growth and sustainability strategies that provide solutions to rural transportation problems. The rural settings may also benefit economically from strategies that evoke greater efficiency. The research will address the goals of reliability, flexibility, and productivity.

Note: The AASHTO Standing Committee on Research directed that the original scope and funds be reduced to that of a synthesis.
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◆ **Project 08-53**

***Best Practices Handbook on Integration of Freight Movement Considerations into State and Local Planning and Project Selection Processes***

Research Field: Transportation Planning  
Source: AASHTO Standing Committee on Planning  
Allocation: \$300,000  
NCHRP Staff: Ronald D. McCready

Nationwide, the traditional planning and project selection processes have not accommodated freight movements and freight needs well. Some areas of the country have made significant efforts to incorporate freight considerations into their planning processes and in developing solutions to facilitate freight movements. The remaining areas of the country need to have guidance provided on how to better incorporate the needs of freight into their planning and project selection processes. The inadequacies of freight planning and programming are found both at the state and the MPO levels, and improvements are needed in procedures, methods, processes, and cooperative mechanisms.

The objective of this research is to identify those areas that have had the greatest success in incorporating freight issues and needs into their planning, project selection, and project development processes; to analyze their approaches to these issues; to determine which approaches have the greatest potential to be successful if applied in other areas; to develop new approaches or variations on the lessons learned; and to produce a practitioner's handbook on approaches, guidelines, and methodologies that can be readily adapted into the mainstream of project selection and programming activities by MPOs and state departments of transportation.

◆ **Project 08-55**

***Real Estate Data Integration for Project Delivery***

Research Field: Transportation Planning  
Source: Washington  
Allocation: \$100,000  
NCHRP Staff: Martine A. Micozzi

Right-of-way issues are commonly identified as one of the causes for project delay and cost increases in project estimates. Some state departments of transportation use data-recording and -storing methods that can be unresponsive to the demands of modern project management, making convenient access of real-time information by multiple users difficult and potentially causing undue delay.

Many departments use Computer-Aided Drafting and Design (CADD) and Computer-Aided Civil Engineering (CAiCE) to develop right-of-way plans. Often, the final approved right-of-way plans are recorded and filed on paper or on Mylar. This information includes desired data such as agency ownership, appraisal information, acquisition status, and property management functions that are important to any array of users; however, the way in which this data is gathered and stored makes access difficult, particularly by those addressing real estate issues, utilities, environmental permitting and mitigation, access management, maintenance, and programming issues. Moreover, the current system of posting right-of-way ownership by hand is obsolete and inefficient and, in the case of a catastrophic event, the information would be irretrievable.

A system needs to be developed that utilizes existing technology and software to integrate information to enable its access by all users. The integration and automation of this data would be beneficial in improving coordination and consistency of data, leading to reduced project delivery delays caused by right-of-way acquisition. In addition, automation and the ability to retrieve this data electronically will provide consistent information to all users, reducing the time and expense needed to ship documents; eliminate repetitive entries; minimize errors due to multiple formats and data entry operators; and ultimately save money for the departments of transportation. Electronic management of real estate information could improve coordination with local jurisdictions and provide appropriate data on agency ownership of property to the public.

The research objective of this project is to develop an estimate of cost and time savings for a Geographic Information System (GIS) that integrates right-of-way plans with other pertinent common transportation management systems. The specific tasks include (1) identifying real estate data needed for development and delivery of highway projects, (2) evaluating options for a GIS utilizing data developed in CADD and CAiCE, (3) identifying options for sharing data amongst users such as a web-based system, and (4) determining how to utilize an imaging system to include land acquisition document images as a GIS layer.

Note: The AASHTO Standing Committee on Research directed that the original scope and funds be reduced to that of a synthesis.
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◆ **Project 09-30A, FY 2005**

***Rutting Performance Model for HMA Mix and Structural Design***

Research Field: Materials and Construction  
Source: NCHRP Project Panel D09-30  
Allocation: \$1,000,000  
NCHRP Staff: Edward T. Harrigan

The objectives of the original Project 9-30 were (1) to evaluate the feasibility of refining the calibration and validation of the performance models incorporated in the NCHRP Project 1-37A mechanistic-empirical pavement design guide with laboratory-measured hot mix asphalt (HMA) material properties for future use in mix and structural design methods, and (2) if further refinement were judged feasible, to develop a detailed, statistically sound, and practical experimental plan and budget to carry out the refinement.

The research agency for Project 9-30 found that field sites and materials were available to further refine the calibration and validation of the performance models with measured materials properties. The project panel then requested development of a detailed experimental plan, budget, and schedule to accomplish this refinement. The experimental plan was reviewed and approved by the panel, which recommended a new project to accomplish the experimental plan for refining the HMA performance model for rutting with measured materials properties.

The objective of this research is to refine the mechanistic-empirical (M-E) performance model developed in Project 1-37A for HMA rutting with measured materials properties and performance data from selected field pavement sections. The following tasks are anticipated to accomplish this objective: (1) conduct a performance model workshop to update as necessary the requirements for measured material property and field performance data in the Project 9-30 experiment design; (2) sample and test HMA and other materials from 30-40 selected pavement sections and conduct related field evaluation and forensic studies; (3) use the measured material properties and pavement performance data to refine the calibration of the HMA rutting model; and (4) provide ongoing support of the M-E Distress Prediction Models (*M-E\_DPM*) database developed in NCHRP Project 9-30 for storing pavement and materials data required for the continued refinement of the HMA distress prediction models in the Project 1-37A mechanistic-empirical pavement design guide.

Note: The AASHTO Standing Committee on Research requested that this continuation be conducted as a new NCHRP project with the updated title above.
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◆ **Project 09-39**

***Development of Procedures for Determining the Mixing and Compaction Temperatures of Superpave Asphalt Binders in Hot Mix Asphalt***

Research Field: Materials and Construction  
Source: New Mexico  
Allocation: \$400,000  
NCHRP Staff: Edward T. Harrigan

The Asphalt Institute (AI) procedure for determining mixing and compaction temperatures for asphalt binders was developed for the standard viscous binders historically used in the United States. The use of modified binders in hot mix asphalt paving has increased significantly. This is particularly true for the high-volume traffic routes. The existing AI mixing and compaction temperatures determination many times requires very high temperatures for these modified binders, which in many cases will damage the binder and cause environmental problems. Cases of blue smoke are very prevalent with the high temperatures predicted for modified binders using the AI procedure. To overcome this problem, it was recommended that the supplier of the asphalt binder should supply the mixing and compaction temperatures. This has led to mixed results. Some suppliers with a great deal of experience have supplied reasonable numbers, but there are many suppliers that have not been able to determine reasonable temperatures for their produced binders.

Temperature has been tied directly to the ability to properly compact hot mix asphalt. Data from We-sTrack have directly shown that proper compaction directly affects rutting and fatigue. If the mix is overheated, problems with heat checking and tenderness can destroy the structure of the pavement, and mixes that are too cold cannot be compacted.

Research in NCHRP Project 9-10 developed several concepts to determine mixing and compaction temperatures for hot mix asphalt. These concepts have been evaluated and appear cumbersome and not well founded on fundamental properties. New procedures for determining mixing and compaction temperatures are needed to select the proper temperature to coat the aggregate and get the mix placed properly on the roadway.

The objective of this research is to develop, recommend, and validate a procedure for determining the mixing and compaction temperature of asphalt binders, both neat and modified, for the production of hot mix asphalt. This research will deliver a reliable, user-friendly procedure for determining asphalt binder mixing and compaction temperatures that is suitable for routine specification use, blind to modification type, and simple to use, as well as having a short completion cycle.

The following tasks are anticipated to accomplish this objective: (1) review the literature both within and outside North America to establish current practice with respect to laboratory procedures for determining the mixing and compaction temperatures applicable to both neat and modified asphalt binders; (2) prepare, as part of the report for Task 1, a design for an experiment to validate the proposed procedure for determining the mixing and compaction process of both neat and modified binders that represents current and expected field practice and considers mixture type and gradation as well as aggregate type (source); (3) carry out the experiment design developed in Task 2; (4) analyze the results of the Task 3 experiment and document them in a final report; and (5) develop a field validation plan for a potential future project.

## ◆ Project 09-40

### *Optimization of Tack Coat Type and Quantity for HMA Pavements*

Research Field: Materials and Construction  
Source: Louisiana  
Allocation: \$350,000  
NCHRP Staff: Edward T. Harrigan

A tack coat is almost always applied just before a hot mix asphalt (HMA) overlay is placed. A tack coat is a simple, relatively inexpensive process. In fact, it is so simple that its real importance is often discounted as it is considered an incidental item in many specifications. Yet, the tack coat is critical to the performance of an expensive HMA pavement layer. An inadequate tack coat product or improper application of a good product can result in expensive overlay failures shortly after construction and, thus, embarrassment to the DOT.

There is an extensive body of literature on tack coat materials and their use. A review indicates that tack coats are placed to bond pavement layers together, and in so doing, provide a monolithic, impermeable layer or prevent slippage of asphalt overlays. However, this view on the function of a tack coat was not unanimous.

A tack coat provides necessary binding between pavement surface layers to make sure that they act as a monolithic system to withstand the traffic and environmental loads. Studies conducted on asphalt pavement interface strength have shown that a strong tack coat binding between the layers of a pavement is critical to transfer radial tensile and shear stresses into the entire pavement structure. On the other hand, no bond or an insufficient bond decreases pavement-bearing capacity and may cause slippage. Insufficient bonding may also cause tensile stresses to be concentrated at the bottom of the wearing course. Such concentrated stress may accelerate fatigue cracking and lead to total pavement failure. This may reflect the recent findings of fatigue cracking being initiated in the wearing course layer.

Recently, several pavements have experienced slippage problems soon after application of a HMA overlay. Sometimes slippage cracks appear at unlikely places (i.e., not intersection approaches or steep grades) such as tangent sections or the top of a hill. There appears to be no relationship between traffic patterns or maneuvers and the locations of the slippage cracks. In severe cases, these slippage cracks develop into fissures several inches wide, and localized delamination of overlays has been experienced. Although no formal studies have been performed, limited evidence indicates that the slippage problems may be associated with the use of excessively diluted emulsified asphalt as the tack coat.

Type, quantity, and application of tack coat are often considered minor issues with relatively insignificant consequences. This has been shown through very expensive errors to be far from the truth. Few guidelines are available for proper selection of tack coat type and quantity and the proper placement. Optimum tack coat type and quantity will, of course, depend on the type and condition of the existing pavement surface. Other factors might include type of the asphalt pavement overlay to be applied, expected permeability of the overlay, traffic loadings (particularly horizontal loadings), and climate.

The objective of this research is to determine (1) the functionality of a tack coat for applications including new construction, overlay, reconstruction, and rehabilitation from the perspective of its applicability to enhance performance of the pavement; (2) bonding/de-bonding mechanisms through controlled shear tests; (3) the cause(s) of the tack-coat-related problems experienced; and (4) optimum application rates and materials for these various functions.

A series of tasks is anticipated to (1) develop test protocols that will rationally establish the optimum type and quantity of tack coat for typical and, possibly, certain non-typical overlay operations; (2) prepare field construction guidelines for tack-coat-type selection, design, application, and quality control testing for optimized treatment of different types of pavement layer surfaces as preparation for an HMA overlay or other HMA layer; (3) document problems related to surface preparation prior to application of an asphalt pavement layer along with successful treatments; (4) demonstrate the use of the guidelines on actual construction projects in several states and monitor construction and resulting performance of the pavements; and (5) prepare instructional materials for at least two pilot courses presented to DOT and contractor personnel.

## ◆ Project 09-41

### *Synthesis Report on Cold Weather Performance of New Generation Open-Graded Friction Courses*

Research Field: Materials and Construction  
Source: Texas  
Allocation: \$250,000  
NCHRP Staff: Edward T. Harrigan

Since the early 1990s, new generation open-graded friction courses (NGOGFCs) have gained wide acceptance throughout the southern and western portions of the United States. Texas DOT's (TxDOT's) version of NGOGFC is referred to as Permeable Friction Course (PFC). TxDOT's first PFC was placed in 1999, and, since that time, approximately 25 PFC projects have been constructed in Texas. PFC mixtures are rapidly gaining popularity due to their ability to reduce the risk of hydroplaning, reduce the amount of splash and spray, reduce pavement noise, improve visibility of traffic striping in wet weather, and improve ride quality. While there are numerous reported benefits of PFC mixtures, there also remains a concern regarding PFC performance in winter conditions. Safety and winter maintenance concerns are often cited as the primary objections to increased use of PFC in Texas.

There are numerous differences between NGOGFC (or PFC) and first generation OGFC. NGOGFC contains approximately 20 percent more asphalt (by volume) than conventional OGFC. NGOGFC is designed to have a minimum of 18-percent air voids, whereas conventional OGFC was not designed based on air voids. Conventional OGFC mixture typically contained between 10- and 15-percent air voids. At the lower air void range, moisture could get trapped within the void matrix of the conventional OGFC. The void structure of NGOGFC allows the mix to be more permeable and less likely to trap water, which could potentially freeze. NGOGFC contain fibers and is heavily modified with polymers unlike conventional OGFC mixes. In addition, NGOGFC mixtures are more open graded than the conventional OGFC mixtures. The open texture allows NGOGFC to get flushed out by high-speed traffic, therefore reducing the potential to get clogged over time. NGOGFC mixtures are typically placed more thickly than conventional OGFC (1.5 to 2.0 inches as opposed to 1.0 inch). The thicker, more open matrix allows the NGOGFC to drain more water off the roadway more quickly than conventional OGFC. All of these changes contribute to the longer reported performance life of NGOGFC; however, it is unclear whether or not this will translate into better performance in winter conditions.

One of the primary reasons for using OGFC mixtures is the safety improvement in wet weather environments. OGFC could potentially provide hazardous driving conditions over a much longer period than traditional dense-graded surfaces. The Fort Worth district of TxDOT reported major "black ice" problems on sections with OGFC mixes in the early 1990s; these problems were reported to last several days more than those on other surfaces. It should be noted that some of the OGFC mixtures placed by the Fort Worth district were polymer modified, and some contained fibers. These modified OGFC mixtures closely resemble TxDOT's NGOGFC mixtures used today. Black ice can form on any pavement under certain climatic conditions; however, when black ice formed on OGFC, it was reported to have formed earlier and lasted longer than it did on traditional dense-graded hot mix surfaces. A common saying associated with the old OGFC mixes is that they were "the first to freeze and the last to thaw." Black ice rarely occurs throughout most of Texas; however, it does appear to be more prevalent in some areas of the state. The primary areas of concern tend to be from the Panhandle region of the state to the Fort Worth/Dallas metroplex region. Problems were also reported during foggy weather or with light rain occurring at near freezing temperatures where the moisture condenses on the coarse OGFC aggregates and then freezes. European researchers have raised similar concerns about winter performance problems. The use of OGFC near the Alps in Austria is now severely limited due to cold weather performance problems.

In addition to the safety issues, concerns have also been raised about the increased maintenance cost of these mixtures due to the need for additional salt and/or sand treatment. Many agencies, particularly the European ones, have adopted innovative methods of maintaining NGOGFCs to ensure free drainage to surface water. It is also known that several agencies are revising their design criteria to improve the performance of

NGOGFC. The use of modified binders and additives has improved the durability of NGOGFCs, but has not solved the potential icing problem.

Research is needed to determine the liability versus benefit of using NGOGFC in geographic regions that are susceptible to numerous freeze/thaw cycles. In addition to monetary costs, potential compromises in safety and convenience to the traveling public need to be investigated before NGOGFC can be used with confidence in geographic regions susceptible to numerous freeze/thaw cycles. As with conventional OGFC mixtures, many engineers believe that it may not be prudent to expand the use of NGOGFC into regions susceptible to freeze/thaw cycles. It is important to quantify the potential risks versus the potential benefits of NGOGFC.

Although no performance problems such as raveling have been reported with NGOGFC, there are still concerns that these mixes could experience the performance problems associated with the old OGFC mixes if the NGOGFC mixes are used in climatic regions susceptible to numerous freeze/thaw cycles. The concerns are the most likely reason that NGOGFC mixes are predominately used in warmer, more arid climates such as the southern and western regions of the United States.

One of the major questions to be answered is whether the NGOGFC mixes will experience the same problems that plagued the first generation OGFC mixes. From a durability standpoint, this question has been addressed fairly well. Research on NGOGFC indicates that the mixes typically last between 10 to 14 years, which is significantly longer than the first generation OGFC mixtures, which typically lasted between 5 and 7 years. Winter maintenance on NGOGFC has not been reported as a major issue. This is likely due to the fact that NGOGFC has not been used much in areas of the country that experience frequent freeze/thaw cycles. Because of the low occurrence of freeze/thaw cycles, generally speaking, the safety benefits of NGOGFC have outweighed the associated inconveniences of winter maintenance and safety concerns related to black ice formation.

The objectives of this research are to (1) develop a synthesis report on the state of the practice in NGOGFC design and performance with a particular focus on winter maintenance issues, (2) determine if and under what conditions NGOGFCs will provide problems, and (3) recommend what design and maintenance options are available to minimize such risk.

The following tasks are anticipated to accomplish these objectives: (1) develop a questionnaire of design, maintenance, and performance issues for DOTs in the United States and selected international agencies; (2) assemble published research information about NGOGFC design and performance, including the numerous studies conducted in Europe, especially Austria, on how to design and maintain these surfacings; (3) use climatic data to identify geographic regions in the United States and Canada that are the most susceptible to freeze/thaw conditions, including their rainfall frequencies and occurrences of black ice; (4) provide recommendations for DOTs on how to maintain NGOGFC in different environmental zones, including the issue of how to avoid clogging or unclog voids due to sanding operations; (5) provide recommendations on design requirements for NGOGFC; and (6) identify topics that should be studied further in a possible future research project.

## ◆ Project 10-68

### *Effectiveness of Pavement Warranties*

Research Field: Materials and Construction  
Source: AASHTO Highway Subcommittee on Construction  
Allocation: \$300,000  
NCHRP Staff: Timothy G. Hess

Highway agencies have used both asphalt concrete and portland cement concrete pavement warranties for many years. Some agencies have been required to do so by state legislation (MI, OH, LA). Other states have used pavement warranties on their own initiative, with the expectation that such warranties would reduce life cycle costs.

The Wisconsin DOT reported significant quality increases and overall cost reductions through the use of a 5-year warranty for asphalt concrete pavements (see: <http://www.dot.wisconsin.gov/library/research/docs/finalreports/tau-finalreports/warranties.pdf>). However, the Colorado DOT's evaluation of six pavement warranty projects with 3-year warranties showed that there was no discernable impact on quality or cost ("Materials and Workmanship Warranties for Hot Bituminous Pavement," CDOT, December 2001, Report No. CDOT-DTD-2001-18).

Research regarding the impact of pavement warranty requirements on the overall quality and cost of the constructed product is needed for both highway agencies and the pavement industry. The emphasis of this research will focus on performance warranties. While some data concerning "materials and workmanship" warranties may be useful, it is anticipated that the majority of useful information will be obtained from highway agencies that have implemented performance warranties.

The objective of this research is to perform a cost-benefit analysis of the use of pavement warranties by performing a cost comparison of pavements constructed under warranty requirements versus non-warranty pavement. In addition, a comparison of quality performance data for warranty versus non-warranty pavement will be performed. It is anticipated that the research will result in the development of recommendations for the appropriate use and application of pavement warranties. These will include (a) project selection criteria, (b) selection of performance criteria, (c) length of warranty, (d) risk allocation, (e) enforcement provisions, (f) retainage, (g) bonding, (h) payment, (i) prequalification, (j) corrective action requirements, (k) dispute review boards, and (l) revision of current guide specifications for pavement warranties.

The proper use and application of warranty provisions is a topic of great importance to state highway agencies and industry. The documentation of cost-effectiveness, lessons learned, revised guide specifications and other recommendations will be very valuable to state highway agencies and the pavement industry.

## ◆ Project 10-69

### *Guidelines for Dowel Bar Insertion in Concrete Pavements*

Research Field: Materials and Construction  
Source: Colorado  
Allocation: \$500,000  
NCHRP Staff: Amir N. Hanna

Dowel bars are used in jointed portland cement concrete pavements to provide load transfer, reduce faulting, and improve performance. Automatic dowel bar inserters have been used to expedite construction and reduce cost. However, misalignment of dowels seems to occur when automatic inserters are used. This misalignment leads to slab cracking and other forms of distress that reduce pavement life and require costly maintenance and repair.

Research is needed to address the issues associated with the use of automatic dowel bar inserters, including the effects of misalignment on pavement performance, the methods for determining dowel bar alignment in the hardened concrete, the means for repairing pavement damage caused by misalignment, and the development of guidance on dowel bar insertion. This guidance will include technical information for use by highway agencies in construction specifications and will help contractors ensure that paving equipment places the dowels in a manner that will eliminate potential adverse effects on the pavement.

The primary objectives of this research study are (1) to develop allowable tolerances for dowel bars in all directions, (2) to identify the types and severity of distresses associated with varying degrees of dowel bar misalignment, and (3) to determine the effects of misaligned dowel bars on concrete pavement performance. To accomplish these objectives, the research will include the following tasks:

1. Search the literature to synthesize information and findings to date on dowel bar insertion, extent of misalignment, effects of misalignment on performance, and methods used for determining dowel alignment in hardened concrete. This information may be obtained from domestic and foreign literature and contact with public and private industry organizations. Determine how many DOTs have specifications that allow them to closely examine the location of dowel bars. Identify the factors that require further evaluation in Phase II.
2. Develop an experimental investigation that involves laboratory testing and field observations to achieve well-supported conclusions. This task includes the following:
  - a. Evaluate the significance of misaligned dowel bars on performance of concrete pavements,
  - b. Recommend methodology to measure dowel misalignment, and
  - c. Recommend and identify methods for reducing dowel misalignment and alleviating the adverse effects of misalignment on performance.
3. Evaluate the effects of construction operations on dowel misalignment.
4. Submit an interim report that includes a plan for the investigations proposed for Phase II. The interim report should be reviewed and approved by the NCHRP before proceeding with Phase II. The investigations in Phase II may include field evaluations to validate/verify other laboratory work.
5. Execute the approved plan for Phase II. Develop guidance that addresses the magnitude of misalignment that can be tolerated without substantial adverse effect on pavement performance, methods for determining dowel alignment in hardened concrete, and methods for repair of pavement damage resulting from dowel misalignment. This guidance should include technical information suitable for inclusion in construction specifications.
6. Submit a final report that documents the entire research effort including an implementation plan for moving the results of this research into practice.

◆ **Project 12-71**

***Develop Design and Construction Specifications for Horizontally Curved Concrete Highway Bridges (with Special Considerations for Post-Tensioned Systems)***

Research Field: Design  
Source: AASHTO Highway Subcommittee on Bridges & Structures  
Allocation: \$350,000  
NCHRP Staff: David B. Beal

Many post-tensioned concrete highway bridges are constructed with horizontally curved alignments. However, the AASHTO Bridge Specifications and other U.S. and international codes do not have guidelines for the design and construction of horizontally curved concrete bridges. In the past 15 years, several problems have occurred. During construction of a post-tensioned, concrete, curved box-girder bridge, the bridge twisted at an end bent, and the inner side of the box-girder lifted off the bearing. The problem was attributed to coupling between superstructure vertical deflection and torsion rotation. The AASHTO Bridge Specifications for concrete bridges do not give specific design guidance. In 2001, AASHTO published the second edition of the AASHTO *Guide Specifications for Horizontally Curved Steel Girder Highway Bridges with Design Examples for I-Girder and Box-Girder Bridges*. Bridge designers need a similar specification for post-tensioned concrete bridges to provide design procedures and construction requirements for horizontally curved concrete bridges.

The objective of this project is to develop guide specifications covering the design and construction of post-tensioned concrete highway bridges. The specifications should be based on current best practice and technology. They should be prepared in LRFD format, which could be adopted by AASHTO. Additionally, design examples should be developed to illustrate the application of the specifications.

Without guidelines from AASHTO, bridge designers will continue to encounter design and construction problems with curved concrete bridges. Construction problems and remedial solutions are generally disruptive to the schedule and result in high cost. The proposed specifications will help address the problems during design and ensure success and economy in construction.

## ◆ Project 12-72

### *Blast/Impact-Resistant Highway Bridges: Effective Design Detailing*

Research Field: Design  
Source: AASHTO Highway Subcommittee on Bridges & Structures  
Allocation: \$1,000,000  
NCHRP Staff: David B. Beal

Design for blast and high-impact loading resistance is a new area for bridge designers. Nevertheless, this field of engineering has been studied for many years as it affects buildings, power plants, and petroleum refinery structures. There is a need to protect the nation's bridges from the effects of blast and high-impact loadings as a result of intentional or accidental explosions and/or ramming by heavy vehicles.

Much research has been done to date documenting the effectiveness of seismic strengthening details for buildings and bridges. Recent university research has begun the investigation of blast loading effects on highway bridges. Future research will identify critical areas and suggest the need to harden certain components of bridges to resist reasonable blast loads.

It has been suggested that known seismic details in highway bridge design, constructed during original construction or as a retrofit, may serve to resist blast loads and provide a predictable level of protection for such structures. The investigation of these known details for this new area of bridge loading could result in efficient design recommendations, delivered in a relatively short time frame.

Research is proposed that will meld together the extensive knowledge of seismic strengthening design for new and existing structures, the equally well-known field of blast resistance design, and the relatively new field of highway-bridge blast resistance design. The research approach will be one of shared knowledge across these fields with special emphasis on the investigation of known seismic details and their effects on blast loading and the effects of strengthening against blast on the seismic resistance.

The objective of this program is to deliver structural detail recommendations to highway bridge designers that will allow for predictable performance and resistance to known levels of blast loading on new and existing structures. These recommendations will include economical and effective designs that will utilize known seismic bridge-strengthening design details. It should be noted that a bridge or a structure should be designed to survive all hazards or the highest probability hazard in that area. A mitigation measure to counter one hazard should not produce a greater risk of damage if another event were to occur. The projects under this program would have dual benefits. Proven details would be effective in countering blast loadings due to terrorist actions and for countering seismic hazards.

There is very high interest in protecting the nation's critical bridge inventory from the effects of blast and high-impact loadings as a result of intentional or accidental explosion and ramming. Known seismic strengthening details could sufficiently harden critical bridge components to resist these effects.

Although it is not feasible to retrofit and strengthen the majority of the nation's 600,000 bridges to resist blast and high impact loadings, work now underway is identifying and assessing the vulnerability of the most critical bridges. Providing an insightful assessment of effective structural security countermeasures based on seismic/impact strengthening concepts is the best starting point in developing efficient and economical recommendations.

The threat from potential blast damage to our nation's bridges, especially from organized terrorist activity, is real and immediate. The economic and human cost of a successful attack could be catastrophic. The potential payoff from this project would be tremendous if it were to lead to design techniques that could shield structures against such attacks.



## ◆ Project 12-73

### *Cyclical-Environmental Degradation Mechanisms in Bonded FRP Repairs of Concrete Beams*

Research Field: Design  
Source: AASHTO Highway Subcommittee on Bridges & Structures  
Allocation: \$500,000  
NCHRP Staff: David B. Beal

Repair and strengthening of structures with FRP reinforcement involves the use of externally bonded sheets or prefabricated laminates. Although the short-term behavior of these applications has been evaluated, research into their long-term performance is incomplete, and durability issues have not been addressed in a comprehensive way. Recent FHWA efforts, such as the Accelerated Test study, and the general Materials Specification for FRP have aimed to develop a framework for determining FRP durability. There is a need, however, to fill out this framework with application-specific guidelines. Because the long-term performance of FRP bonded repairs is very sensitive to storage, handling, installation, and curing procedures, the priority and initial focus of application-specific guidelines has been in these areas. NCHRP Project 10-59A, with the objective of developing construction specifications for bonded repair, is the result of this initial focus. In addition to durability issues, design issues such as shear-flexural interactions, anchorage and end detailing, and ductile versus non-ductile behavior in the repaired structure are now being examined more closely. An FHWA study at the University of Missouri -- Rolla (UMR) is now being conducted to address, in detail, a number of these design issues. Guidelines for designers will be developed as part of the UMR project. The comprehensiveness of both sets of guidelines depends on the comprehensiveness of underlying research, however. One area that has not been studied comprehensively, primarily because of cost, is the behavior of these bonded systems under cyclical loads. This is an important aspect of behavior in any adhesively bonded system and is generally the subject of qualifying tests where these systems are being considered. Cyclical loading on bonded FRP systems can be expected to be significant. In addition to the original application of repairing deteriorated beams, an important emerging motivation for the use of bonded FRP has been to upgrade the live load capacity of a beam because of increased service loads (i.e., growing traffic volumes and increased vehicle weights).

The objective of this project is to extend guidelines for the design of bonded FRP repair of concrete beams to include the effects of cyclical loads in adverse environments. Laboratory testing will be conducted to provide the required background materials for these guidelines. The contractor will collect and review all literature, research findings, performance data, and current practices relative to behavior of bonded FRP-repaired concrete beams under cyclical loads and in adverse environments. Research will be conducted to identify factors that affect the long-term performance of these systems. Mechanisms by which environmental factors drive or accelerate deterioration of the adhesive resins, the interface between the resin and the concrete, and the interface between the resin and the FRP (in plate systems) will be identified. A test matrix will be developed to accelerate these effects. The contractor will need to determine which environmental factors may be applied before cyclical loading and which will have to be applied during cyclical loading. Typical environmental factors would include freeze-thaw cycling, exposure to UV, high relative humidity, and exposure to salts. Factors of safety will be calculated, and failure criteria for bonded repairs will be developed in the form of maximum acceptable de-bond areas by pattern, size, location, and orientation. Cyclical mechanical load tests will be conducted at full scale to verify the factors of safety and to develop design guidelines for various repair objectives. Design variables, to be factored into test specimens, include crack widths and crack spacing (with and without epoxy injection in the cracks); compressive strength of concrete; FRP strength, stiffness, and elongation; number of plies of FRP; ply orientation and cutoff lengths; end detailing of FRP; and lap splice length (including no lap). Finally, the contractor will develop modifications to the draft AASHTO Design Specifications for Bonded Repair of Concrete Structures, now being produced at UMR. Where appropriate, the contractor will also examine and recommend modifications to the AASHTO Construction Specifications for Bonded Repair and Retrofit of Concrete Structures Using FRP Composites developed under NCHRP Project 10-59A.

At present, there are no fatigue-based guidelines for bonded FRP repair of concrete structures available to designers or bridge owners. Behavior under cyclical loads is an important aspect of behavior in any adhesively bonded system and is generally the subject of qualifying tests where these systems are being considered. Cyclical loading on bonded FRP systems on highway bridges can be expected to be significant. In addition to the original application of repairing deteriorated beams, an important emerging motivation for the use of bonded FRP has been to upgrade the live load capacity of a beam because of increased service loads. Although the use of bonded FRP in the repair of concrete structures is expanding rapidly, this critical issue has not been studied in a comprehensive way. The principal long-term benefit of this research is longer service life for concrete bridge beams repaired with bonded FRP systems. This will reduce the annual backlog for beam or bridge replacement, resulting in lower costs to maintain or improve the transportation system. The results of this research will be used by bridge owners, bridge designers, contractors, specialty (FRP inspection/repair) subcontractors, and FRP manufacturers. Research results will be implemented with a modification of the draft AASHTO Design Specifications for Bonded Repair of Concrete Structures now being produced at UMR. These specifications, when combined with the AASHTO Construction Specifications for Bonded Repair and Retrofit of Concrete Structures Using FRP Composites now being produced under NCHRP Project 10-59A, will form a comprehensive set of guidelines for the application of this technology.

## ◆ Project 14-15

### *Performance Data for Maintenance Actions at Highway Structures*

Research Field: Maintenance  
Source: Kansas  
Allocation: \$500,000  
NCHRP Staff: Amir N. Hanna

Research has shown that preventive maintenance is the most cost-effective strategy for preservation of transportation assets. There are many different preventive maintenance actions that may be applied, but it is difficult to compare alternative methods and products. Rates and intervals of application are usually determined by trial and error. When new methods or products are developed, their effectiveness is known only after several years of use. Factors such as traffic, climate, and age of the structure affect the performance of preventive maintenance actions, though quantitative measures of their influence may not be available.

Too often, transportation agencies experiment independently to develop strategies for preventive maintenance. Better strategies will be achieved when transportation agencies can share information on use and performance of preventive maintenance methods. To be shared, data on methods, costs, and performance must first be standardized. Quantitative data on preventive maintenance actions, their application, costs, and useful life are needed for rational cost/benefit evaluation.

It is proposed that a specification be developed for a national inventory system for preventive maintenance actions for highway structures. The maintenance inventory system will establish a standard data record for actions that includes description of methods, basis of measurements, costs, impacts on traffic operations, age and condition of structure at the time of the maintenance action, age and condition of the structure in subsequent inspections, and age at renewal or reapplication of a preventive maintenance action. Quantity and condition data will identify the bridges and elements addressed by the actions, following the AASHTO Guidelines for Commonly Recognized Elements. The maintenance inventory will support cost/benefit evaluation for actions, provide information needed in life cycle cost analysis of preventive maintenance programs, and support evaluations of indirect costs through data fields addressing duration of maintenance projects and impacts on traffic operations.

To develop a maintenance inventory system, the research will first examine existing practices in preventive maintenance programs and reporting. Following this, a maintenance inventory system will be developed that is compatible with existing practices. This design will be reviewed and amended by a working group of representatives from transportation agencies. A first product will be a guide specification for creation of a national inventory system, including a standardized data schema. The second phase of work will design and launch a national repository for maintenance data collected according to the specification. This work may include web site development and software for data quality assurance and analysis as well as documentation and guidance on the use of this valuable resource.

The project will build on the results of *NCHRP Synthesis 227: Collecting and Managing Cost Data for Bridge Management Systems* (1996). The project will assess requirements for accuracy, precision, timeliness, and quality of cost data. It will evaluate relevant methodologies for converting maintenance inventory data into the cost factors that will be useful to bridge management systems.

## ◆ Project 15-28

### *Modernize and Upgrade CANDE for Analysis and LRFD Design of Buried Culverts*

Research Field: Design  
Source: AASHTO Highway Subcommittee on Bridges & Structures  
Allocation: \$450,000  
NCHRP Staff: David B. Beal

First introduced in 1976 under the sponsorship of FHWA, the CANDE computer program is the premier design and analysis tool for all types and sizes of buried culverts. CANDE is a public domain finite element program, available through McTrans, and is widely used by state DOTs, industry, consulting firms, and universities in the United States, Canada, Europe, Africa, and Australia. CANDE is applicable to all types of culverts, including corrugated steel, corrugated aluminum, reinforced concrete, and thermoplastic pipe materials, as well as special culvert shapes and installation such as long spans. CANDE is the only program of its kind dedicated to soil-structure analysis of culvert systems. It is an indispensable tool for state DOT designers when they are confronted with specialized installations that do not conform to simplified or routine design conditions, a problem that occurs all too often in practice.

CANDE was last updated and enhanced in 1989 and operates in a batch-mode environment. Since then, significant changes have occurred in computer technology, such as window-based programming environments. Moreover, recent NCHRP studies have introduced new design criteria and analysis techniques, which have been incorporated into AASHTO LRFD design specifications for buried culverts. Also, new culverts materials and improved constitutive models are now being developed and utilized in the culvert community. Accordingly, there is a definite need to modernize and update CANDE to incorporate all of these recent innovations and changes. CANDE is a significant research tool, but, just as importantly, it is a widely used design tool for challenging culvert installations.

While simplified design methods are available for designing “simplistic or production level” culvert installations, finite element analysis provides the only rational available technique to analyze nonstandard or specialized culvert systems such as long spans or systems with special soil conditions and/or new concepts and materials. These installations are usually very expensive; therefore, state DOTs along with their design consultants need a reliable and well-accepted analytical tool to develop and verify a safe yet economical design. CANDE stands alone as the only dedicated finite element program developed for the soil-structure analysis of buried culverts. Thus, it is highly important to upgrade the CANDE program for these applications.

The objective of this research is to modernize and upgrade CANDE. Specifically, the objectives are to employ modern computer technology by providing a windows-based, menu-driven format for data input generation and windows-based graphics for real-time control of data output and to convert CANDE coding to a modern computational language supporting windows. The scope of CANDE applications will be enlarged by incorporating AASHTO LRFD design/analysis capabilities, by increasing program size capacity and installing a bandwidth minimizer, by providing capability to analyze multiple structures and eliminate connected structure restriction, and by including SI and Customary U.S. units as input and output options. The analytical capabilities will be enhanced by incorporating large-deformation capability for generalized buckling predictions.

While CANDE is widely used, it was last updated in 1989 and operates only in the DOS mode, which will soon become unavailable on personal computers, and there is no culvert design or analysis software currently available to replace it. New capabilities and technology must be incorporated into CANDE in order for it to remain available for state DOTs and their consultants for difficult and expensive culvert designs.

◆ **Project 15-29**

***Use of the AASHTO LRFD Bridge Design Specifications to Determine Load Distribution for the Design of Buried Structures***

Research Field: Design  
Source: AASHTO Highway Subcommittee on Bridges & Structures  
Allocation: \$350,000  
NCHRP Staff: David B. Beal

Design and evaluation of buried structures requires the determination of vertical earth loads and vehicular live loads transmitted through earth fills. Force effects due to vehicular live loads are determined by approximate methods. The AASHTO Standard Specifications specify use of a surface point load that is spread through the underlying soil over an area having sides equal to 1.75 times the depth of cover. This is applicable for cover depths greater than 2 feet.

The AASHTO LRFD Specifications assume that the live load is distributed through the soil cover by 60 degrees from the horizontal spreading rule. This is for cover depths greater than 2 feet. At 3.5 feet of cover, this change has the effect of increasing live load pressures on buried structures by nearly 70 percent over that obtained by the Standard Specifications. When combined with the increased dynamic load allowance, this increase is even higher. The appropriateness of these changes for load distribution for buried structures needs to be further investigated because they have a significant effect both on the design of new buried structures and the rating of existing ones by the LRFD philosophy. Most existing buried structures designed to the Standard Specifications may not rate when checked using this increased force effect.

The AASHTO LRFD load factors used for the design of buried structures result in designs that are far more conservative than if the AASHTO Standard Specifications were used. The objective of this project is to develop recommended revisions to the AASHTO LRFD Bridge Design Specifications for live load distribution to buried structures. Design equations and calibrated load factors are needed.

◆ **Project 15-30**

***Median and Median Intersection Design for High-Speed Facilities***

Research Field: Design  
Source: AASHTO Taskforce on Geometric Design  
Allocation: \$200,000  
NCHRP Staff: B. Ray Derr

The safety and operational characteristics of medians and median intersections on high-speed facilities continues to present challenges to designers from a consistency of application perspective. Recent research relative to median intersection design (*NCHRP Report 375*, 1995) focused primarily on the desirable width of medians at intersections on divided highways with partial or no control of access. Information provided in the AASHTO Green Book relating to design of the median cross section, median intersection design, and the cross-over design needs to be reviewed and updated to reflect best practices for safety and operation.

The objective of this research is to review the current AASHTO median and median intersection design information for high-speed divided highways with partial or no control of access and to recommend appropriate modifications to the AASHTO Green Book. The review should include the following: median design and landscaping, including plantings for attenuation of errant vehicles such as crossover intrusions; truck accommodation in median designs and crossovers; design of the median crossover itself (width and configuration); and turn lane design associated with the crossover.

The research should review current AASHTO guidelines and actual practice and identify areas where guidance is lacking or needs to be expanded/supplemented. With these areas identified, the researcher should identify potential sites to provide needed data and develop new design guidance to reflect optimal safety and operational characteristics.

## ◆ Project 15-31

### *Design Guidelines for Acceleration and Deceleration Lanes for Freeways*

Research Field: Design  
Source: AASHTO Task Force on Geometric Design  
Allocation: \$450,000  
NCHRP Staff: B. Ray Derr

There is a need to investigate the geometric design and the criteria used in designing the freeway ramp terminals used daily to provide connections to our freeways at interchanges. The acceleration lane length tables developed for the 1965 AASHO Blue Book are still in use today with only minor adjustments and do not reflect the capabilities of the current vehicle fleet.

The design values for acceleration and deceleration lanes at freeway ramp terminals in the AASHTO Green Book (2001) rely primarily on research conducted in the late 1930s and early 1940s, predating the development of the Interstate system. The studies relied entirely on passenger cars for acceleration and deceleration rates, without consideration of trucks and busses due to the assumption that the acceleration distances would be “entirely out of reason.” Vehicle characteristics have changed since the original research. For example, the weight-to-horsepower ratio for trucks in 1965 was 400 lb/hp compared with the currently used ratio of 200 lb/hp and all vehicles studied had manual transmissions, because automatic transmissions were rare at that time.

The merge was assumed to occur when the passenger car speed was within 5 mph of the average running speed on the freeway. An additional assumption used for the design of ramp terminals was an acceleration rate of approximately 60 percent of the full capability of the passenger car and decreasing in a linear fashion as speed increased.

The objective of this research is to examine the current procedures, concepts and criteria for the design of acceleration and deceleration lanes for freeway interchanges to identify areas where guidance and criteria are outdated, lacking, or need to be expanded and to recommend revisions to the appropriate sections of the Green Book. With these areas identified, the researcher should gather additional data, if needed, and develop new design guidance and criteria to reflect optimal operational and safety characteristics for the current vehicle fleet.

Tasks to be performed include (1) determination of the advantages and disadvantages of the two types of ramp terminals based on operation and safety for both single and multi-lane ramps; (2) determination of the assumptions or basis for new entrance and exit terminal design to include consideration of speed of ramp traffic at merge, the location along the ramp or auxiliary lane where the motorists must select a gap in which to merge, and the use of decision sight distance for drivers on the ramp; (3) vehicle types as the basis for design; (4) acceleration and deceleration (braking and coasting) rates based on the current vehicle fleet; (5) lengths of acceleration and deceleration lanes, including adjustments for grade; and (6) appropriate taper lengths for use in design. The researcher’s recommendations should be presented in a format usable by the AASHTO Technical Committee on Geometric Design in a future edition of the Green Book.

◆ **Project 17-32**

***Balancing the Benefits and Tradeoffs of Shoulder Rumble Strips and Centerline Rumble Strips on Divided and Undivided Highways in Urban and Rural Areas***

Research Field: Traffic  
Source: Washington  
Allocation: \$400,000  
NCHRP Staff: Charles W. Niessner

Shoulder rumble strips have demonstrated their effectiveness in reducing run-off-the-road collisions on rural divided highways throughout the U.S. Although information is limited, there is evidence that centerline rumble strips are an effective counter-measure for reducing centerline crossover collisions. Because they have proven to be such cost-effective counter-measures in reducing collisions, state DOTs and local agencies want to expand the use of rumble strips along the shoulders of divided or undivided highways and along the centerline of undivided highways. However, the shoulders of the undivided highway system, particularly in urban areas, are a more diverse environment, with increased numbers of bicyclists, pedestrians, mail carriers, and school busses using the shoulder. These areas also present greater variability in shoulder widths and pavement depths. Further, shoulders are used for detours during construction and maintenance operations, causing vehicles to drive over the rumble strips resulting in potential operational problems. There are unanswered questions regarding whether the installation of shoulder rumble strips on undivided highways leads to drivers overcorrecting on the shoulder and crossing over the centerline into oncoming traffic. The noise produced by rumble strips can affect adjacent residents. For centerline rumble strips, there are similar concerns plus a concern about pavement durability at centerline joints. Installing rumble strips to reduce run-off-the-road or centerline crossover accidents, with no consideration of impacts to other users, may lead to unintended outcomes.

Research is needed to quantify the impacts to all users with consideration of the shoulder width, urban versus rural, pavement depth, and, in the case of centerline rumble strips, passing versus no-passing zones. It is expected that the research will produce guidance on what considerations to evaluate in reaching decisions regarding the appropriateness of rumble strips on undivided and divided highways in urban and rural areas.

The research tasks would include (1) Literature Search--A literature search would be conducted to collect information on existing policies governing evaluation of centerline and shoulder rumble strips on undivided and divided highways; (2) Data Gathering and Evaluation--Data would be gathered and analyzed to quantify effectiveness in reducing run-off-the-road and centerline crossover crashes in urban and rural environments with different shoulder width configurations; effects on pedestrians, bicyclists, and other shoulder users; and effects on the service life of the facility; and (3) Design Guideline Development--Recommendations would be developed for use in updating AASHTO guides.

The need exists for a guide addressing the appropriateness of rumble strips. With the previous successes of rumble strip installations, it is important that policies identify the value for divided and undivided highways in urban and rural areas and that designers have full knowledge of the benefits and tradeoffs, so that the benefits are maximized while minimizing unintended side effects.



◆ **Project 17-33**  
***Evaluating Highway Safety Grants***

Research Field: Traffic  
Source: Maryland  
Allocation: \$600,000  
NCHRP Staff: Martine A. Micozzi

In 2002, the U.S. DOT reported 42,815 fatalities and nearly 3 million injuries resulting from highway crashes nationwide. The National Highway Traffic Safety Administration (NHTSA) estimates that highway crashes cost our society \$230.6 billion a year. To reduce these injuries and fatalities, billions of dollars are invested every year to engineer and construct improved and safer infrastructure, enforce traffic safety laws, and educate users of the nation's highway system on safe practices.

Each year, hundreds of millions of dollars are spent on behavioral highway safety grants without sufficient knowledge of the benefits. There is a dearth of comprehensive guidance on good practices for assessing the impact of a broad variety of safety campaigns and other safety initiatives funded by highway safety grant programs. Having such information is needed by states in the development of their respective highway safety programs to contribute to achieving the goals of AASHTO's Strategic Highway Safety Plan.

In addition to other safety grant and transfer programs, the Transportation Equity Act for the 21st Century (TEA-21) authorized \$932.5 million over 6 years for the State and Community Highway Safety Grant Program, commonly referred to as the "Section 402 program." The purpose of the Section 402 program is to support initiatives to reduce traffic crashes and resulting deaths, injuries, and property damage. Section 402 funding is used to address a broad spectrum of national-priority, non-infrastructure, safety initiatives at the state and local level. These efforts address such issues as alcohol and drug countermeasures, occupant protection, police traffic services, motorcycle safety, pedestrian and bicycle safety, and speed control, among others.

The less tangible nature of many of the safety initiatives funded by highway safety grant programs such as public awareness campaigns, start-ups of new safety programs, and improved operator training makes it difficult to assess and quantify the benefits resulting from these programs. For example, how does one most appropriately measure the effects of an initiative on operator/user behavior? With what degree of accuracy can one attribute a reduction in the frequency and/or severity of crashes to such an initiative? How can the benefits of a specific initiative be evaluated in a complex environment, where many strategies are being employed simultaneously to change unsafe behavior?

This research addresses the lack of scientifically obtained/derived knowledge about the efficacy of various behavioral countermeasures that is available to guide the development, implementation, and funding of such programs at the state and local levels. The project will explore the cost-effectiveness of various behavior-changing strategies/techniques currently in use, or being developed, to fulfill the goals of the AASHTO Strategic Highway Safety Plan. The final product will provide guidance that will assist states and local governments in selecting programs, projects, and activities that have the greatest potential for results.

## ◆ Project 17-34

### *Prepare Parts IV and V of the Highway Safety Manual*

Research Field: Traffic  
Source: AASHTO Standing Committee on Highway Traffic Safety  
Allocation: \$200,000  
NCHRP Staff: Charles W. Niessner

The Transportation Research Board has a ground-breaking initiative currently underway to develop a Highway Safety Manual (HSM). The HSM will serve as a tool to help practitioners make planning, design, and operations decisions based upon safety. It will serve the same role for safety analysis that the *Highway Capacity Manual (HCM)* serves for traffic operational analysis. The purpose of the HSM will be to provide the best factual information and tools in a useful and widely accepted form to facilitate the explicit consideration of safety in decision making. The recently completed NCHRP Project 17-18(4) produced a detailed annotated outline for the first edition of the HSM, as well as a plan for a research program needed to develop that first edition within five years. TRB has formed a Task Force on Development of the Highway Safety Manual to guide the HSM initiative.

The emphasis of the HSM will be on the development of quantitative tools. Therefore, NCHRP 17-18(4) produced a proposed draft for one of the key modeling sections of the HSM (Two-lane Rural Highways), based primarily upon work funded by the Federal Highway Administration. Work funded by the Federal Highway Administration is also expected to provide significant input for developing models that can, with further research, be extended and refined to apply to analysis of multi-lane rural highways. In addition, NCHRP Project 17-26, "Development of Models to Predict the Safety Performance of Urban and Suburban Arterials," has been funded and work has begun.

The recent and ongoing work described above is focused upon developing the safety prediction models or algorithms needed to make quantitative estimates of the safety performance for specific highway types. Although such quantitative predictions are central to the vision for the HSM, the Manual will provide much more to the user. In particular, Part I of the HSM will introduce the Manual and provide an overview of its functions and applications, as well as present some fundamentals of highway safety for the user. Part II will present a summary of knowledge regarding safety effects of various aspects of roadway design and operation, in a form that users can readily apply to their work.

Just as the *HCM* evolved in complexity and the ability to reflect more of the factors involved, so it is expected to be with the HSM. The initial modeling effort is expected to result in an order-of-magnitude change in the approach to highway safety analyses. HSM Part I (Introduction) and Part II (Knowledge) will provide information on the use of the HSM and summarize knowledge about highway safety that is of critical importance to HSM users. Parts I and II will provide essential material to allow users to understand and apply the quantitative estimation procedures in Part III (Predictive Methods) effectively. The development of HSM Parts I, II, and III has been funded in NCHRP Projects 17-26, 17-27, and 17-29.

Parts IV (Safety Management of a Roadway System) and V (Safety Evaluation) will also provide valuable guidance to the user on incorporating safety considerations into highway planning, design, and operations. The development of HSM Parts IV and V is the major outstanding need to prepare draft materials for the first edition of the HSM. This project is an integral part of the work plan for the first edition HSM developed by the TRB HSM Task Force and constitutes Project C-5 in that work plan. The work plan approved by the TRB Task Force is available for review at <http://www.highwaysafetymanual.org>.

The objective of the research is to prepare Parts IV and V of the Highway Safety Manual. These two sections will cover safety management of roadway systems and safety evaluations. HSM Part IV and Part V should be developed in the research project and placed in as near final form as possible. The outline of Parts IV and V should follow the latest available guidance from the TRB Task Force. It is expected that Part IV (Safety Management of a Roadway System) will include chapters on identification of sites with promise, diagnosis of the nature of safety problems at specific sites, selection of countermeasures, economic appraisals of sites under

consideration, and prioritization of improvement projects. Part V (Safety Evaluation) will contain information on estimating the safety effect of implemented interventions.

The research will prepare a draft of Parts IV and V in a form that is consistent with the plans for the rest of the HSM. In developing Part IV and V, the research shall conduct critical reviews of published literature and maintain liaison with ongoing research projects to assemble the most complete and up-to-date set of current knowledge. The following tasks are anticipated to be needed:

1. Review guidance available from the Task Force on safety management systems and safety evaluations, as well as results of surveys which include indications of priority needs of potential users.
2. Identify and acquire all appropriate literature, including literature from international sources.
3. Develop criteria for assessing the validity and applicability of the results reported and the procedures described.
4. Assess the sources and select those considered appropriate to use.
5. Identify current highway agency practices for the safety management and evaluation procedures to be covered in Parts IV and V and identify software in current use or under development to implement these procedures. Determine best practices in safety management and evaluation for incorporation in the HSM and assess how HSM Parts IV and V can be developed to encourage the use of these best practices in conjunction with software. Use available software, if feasible and appropriate, to generate examples for use in HSM Parts IV and V. (No software development is to be done as part of this project.)
6. Prepare a prototype and representative chapter for Parts IV and V, for review and approval by the project panel and the TRB Task Force.
7. Develop a set of text, tables, graphs, and formulas which summarize the assembled knowledge, combining sources wherever feasible.
8. Prepare draft chapters for Parts IV and V of the HSM.

State and local highway agencies, and others responsible for the road system, do not currently have very useful tools for reflecting safety in their decisions. This diminishes the weight placed on safety considerations in these decisions. When difficult choices must be made, greater confidence is often placed on predictions of such factors as cost, operational impacts, and environmental impacts, which are expressed in quantitative terms. There is a significant need to improve the explicit role of highway safety in making decisions on roadway planning, design, and operations. To receive appropriate consideration, safety needs to be dealt with in quantitative terms in the design and planning process. The HSM will serve this purpose.

The TRB Task Force seeks to target the HSM primarily to those on the front line of daily decision-making within state highway agencies, as well as local organizations such as municipal agencies and MPOs. This would include analysts anticipating the impact of planning, design, operational, and maintenance decisions. The manual will also serve a number of secondary users as well, and the material should be produced with these secondary users in mind.

The HSM is seen as a tool that will grow and evolve over time in a number of editions. It will take advantage of what is learned at each step, advances in related sciences, and new understanding of user needs, while reflecting the constantly changing demands upon the highway safety professionals whom the HSM is intended to serve. It is the intent of the Task Force to establish a continuing, coordinated, research and development effort in which it is hoped that NCHRP will continue to play a pivotal role to produce the first edition of the HSM.

## ◆ Project 19-07

### ***GASB 34 - Methods for Condition Assessment and Preservation***

Research Field: Administration  
Source: AASHTO Administration Subcommittee on Transportation Finance  
Allocation: \$250,000  
NCHRP Staff: Gwen Chisholm-Smith

While conducting NCHRP Project 19-4, “A Review of DOT Compliance with GASB 34 Requirements,” the Research Panel became aware of a number of issues and concerns of the state DOTs requiring additional information and research. This is not surprising. As acknowledged by GASB Chairman Tom L. Allen, “*Statement 34 is the most significant change to occur in the history of government financial accounting.*” It is to be expected that a change of this magnitude will require several years for affected agencies and their financial and management systems to fully absorb and make necessary adjustments. More specifically, there is a need for more detailed research on condition assessments and preservation methods that will (a) allow more integration of asset management data into the financial statement reporting process and (b) lead to better preservation results.

Our research has shown that many transportation and finance officials believe that GASB’s depreciation of infrastructure is meaningless because it does not reflect how assets are managed or used. Nevertheless, our research also demonstrates that many DOTs (in fact, a slight majority) selected the depreciation approach for FY 2002 because of a lack of comfort with condition assessments and preservation modeling and the uncertainty of having to shift from the modified approach to the depreciation model if targets are not met.

Some have suggested that if a more consistent method for condition assessments and preservation could be developed, a long-term approach to reporting condition assessment data in the financial statements that would relate to funding of preservation (similar to how pension expense is now reported by employers) would be more meaningful than the current modified approach. If GASB ultimately were to approve an infrastructure financial reporting approach similar to that used for pensions, then a number of improvements suggested below might be implemented.

The methods so developed would NOT be intended to compare state DOTs--indeed, pension reporting does not compare pension plans of governments. Rather, the methods would be intended to bring consistency in approach of measuring how well the DOT is preserving infrastructure in comparison to where the DOT wants to be with preservation. Unlike the current modified approach, the financial statements would directly report estimated preservation requirements as expenses, rather than identifying that information reported as “required supplementary information.” This is exactly the type of measurement pension financial statements report--comparing funding with requirements based on one of several parameters.

In order to assist in this process, we suggest that the list of specific topics below warrant additional investigation. We further suggest that this investigation be conducted with formal involvement of the GASB staff in order to enhance its effectiveness.

The specific tasks proposed for additional research, each with objectives, are listed below. For all of these tasks, the intention is not to identify the single “right” answer, but rather to develop a menu of best practices for the DOTs to select from based upon their specific circumstances. This approach is consistent with current GASB philosophy, which relies upon principle-based standards, rather than a more prescriptive detail-oriented approach.

### **Methods for Condition Assessments**

GASB developed a “modified” rather than a “comprehensive” approach for condition assessment reporting because consistent condition assessment methodology has not yet been developed.

The objective of this task would be to develop more detailed, but still voluntary, methods for consistent condition assessments and disclosures that could (a) prove sufficient for future comprehensive GASB recognition and (b) result in more comfort and acceptance by DOT officials.

### **Linking Condition Targets to Required Expenditures**

Virtually all modified approach states experienced difficulty in estimating the expenditure level necessary to achieve targeted conditions. In theory, such estimates should be available from asset management systems (e.g., the PONTIS bridge management system). However, the DOTs report that the current stage of deployment of such systems is not sufficiently mature to generate reliable estimates, with availability of data a particular problem.

A second problem is that the GASB 34 definitions of expenditure categories are not consistent with the definitions traditionally used in the management systems (and in DOT budgeting). Due to these two factors, the DOTs' estimates of required expenditures are based more on historical funding and budgetary patterns, rather than an analytically based estimate as GASB had anticipated. As the deployed capabilities of the management systems improve over time, it is likely that this issue will become less troublesome. In the near term, however, there is a discrepancy between GASB expectations and DOT realities.

The objective of this task would be to identify practical near-term methods of arriving at an expenditure target and comparing that target with actual expenditures in a manner that meets GASB's objectives while still being consistent with the capabilities of DOTs' management systems as currently deployed.

### **Cost Categories--Capitalized Versus Expensed**

As noted above, there is a discrepancy between GASB 34 cost categories and what is traditionally used by DOTs. The GASB 34 guidelines use a functional approach to these categories--maintenance costs achieve the original design life, preservation costs extend that design life but do not increase capacity or service, and capital costs increase capacity or service. However, the traditional DOT definitions relate more to type of construction--a full reconstruction project is viewed as capital whether or not lanes are added; a resurfacing project is viewed as preservation whether or not there are ancillary safety benefits. These definitions are significant because they determine whether costs are to be capitalized or expensed in the financial statements. In particular, preservation costs are to be expensed in modified approach states but our research indicates that this is often not the case.

GASB has suggested that a potential solution is to allocate costs within a project to the three categories, but this is strongly resisted as impractical by the DOTs who typically must account for hundreds, if not thousands, of projects each year. Some DOTs have suggested that the difference between the two approaches is not material for the purposes of financial statements.

The objective of this task would be to first assess the materiality of the difference between the two approaches by analyzing the annual construction program of a representative (but small) state. If the difference is material, the next step would be to develop a more sophisticated approach to cost categorization that would be meaningful to DOTs while still satisfying GASB objectives. Application of FHWA definitions would be investigated.

### **Additions and Retirements**

Most DOTs had difficulty in accounting for additions to and retirements of infrastructure assets in their financial statements. They have, of course, traditionally tracked such changes in their physical inventory systems, but prior to GASB 34 there was no reason to create a linkage to costs reported in the accounting system, disaggregated by asset class. Some DOTs (e.g., Michigan) were able to address this requirement through the use of work type codes.

The objective of this task would be to further develop the approaches employed by Michigan and others into a tool for additions and retirements that could be applied by many states.

### **Required Shift to Depreciation**

Several DOTs questioned the wisdom of requiring a state to shift from the modified approach to depreciation if the condition targets were not achieved. They noted that a recurring failure to achieve targets indicated a problem, one that warrants public scrutiny. Requiring a shift to depreciation seems to suggest that, in effect, the solution to the problem is to stop disclosing it. (However, GASB notes that the logic behind requiring governments to begin depreciating if the infrastructure is not at or about the established condition level, is that because the condition of the asset has dropped below a sustainable level, it can no longer be preserved indefinitely. Its useful life has gone from indefinite to finite.) The DOTs suggest that states be permitted to continue using the modified approach and that the shortfall continue to be reported, much as a shortfall in a pension program is reported.

The objective of this task would be to devise a method by which a state not meeting its condition targets could continue to use the modified approach, if it so chose. This method, which ultimately would have to be approved by GASB, would involve directly reporting preservation information in the financial statements, as discussed above.

### **Potential Effect on Bond Rating**

Several local governments have reported improved bond ratings as a result of preparing financial statements in accordance with the modified approach. Although a comprehensive review of local governments' compliance with GASB 34 is outside the scope of current or proposed NCHRP research, these reports are clearly of great interest to the state DOTs. If confirmed, there could be a substantial effect on the manner in which state DOTs comply with GASB 34. Of equally great interest would be to gain insight into the bond rating agencies' thinking as they determine whether a particular presentation in Management Discussion & Analysis is sufficiently persuasive to warrant an improved rating.

The objective of this task would be to confirm whether improved bond ratings have indeed occurred due to adherence to the modified approach and, if so, to better understand what factors are important in the bond rating agencies' review.

Near the conclusion of NCHRP Project 19-4, the panel began hearing anecdotal reports of local governments receiving improved bond ratings after preparing FY02 financial statements in accordance with GASB 34's modified approach. The bond rating agencies do not officially disclose the reasons for rating adjustments, but the governments involved appear convinced that the modified approach was responsible. They used the Management Discussion & Analysis to disclose that they were effectively preserving their infrastructure and thereby were not accumulating unfunded liabilities for future generations to address. They believe that the rating agencies were favorably impressed by this analysis and adjusted ratings accordingly. If confirmed, this development has significant implications for the DOTs' approach to GASB 34.

◆ **Project 24-27**

***Recommendations for the Adoption of Bridge Scour Research by State Highway Agencies***

Research Field: Soils and Geology  
Source: AASHTO Taskforce on Hydrology & Hydraulics  
Allocation: \$350,000  
NCHRP Staff: Timothy G. Hess

Since 1987 significant resources have been devoted by state DOTs and other entities to research of bridge foundation scour. Research has been conducted in the areas of (a) prediction of scour at bridge piers and abutments, (b) the selection and design of bridge scour countermeasures, (c) streambank protection, and (d) the analysis of river systems and methodologies for predicting river migration.

In 1997, NCHRP Project 24-8, “Scour at Bridge Foundations: Research Needs,” was completed. NCHRP Project 24-8 was initiated because of the need to develop a comprehensive strategy to identify and guide bridge-scour-related research. In developing this strategy, it was necessary to assess the validity and applicability of past and present research related to bridge scour and fluvial system instability; define the state of practice; identify gaps, deficiencies, and potential improvements in current scour technology; and make recommendations for future research. As a result of this project, a number of research studies have been completed by NCHRP. In addition, research not necessarily related to the strategy developed in NCHRP Project 24-8 has been conducted by agencies other than NCHRP. There is a need for research to critically examine the results of scour research completed or initiated in the last 10 years and make recommendations as to whether the research should be adopted and implemented by state highway agencies.

The objective of this research is to critically evaluate the results of scour research completed in the past 10 years and make recommendations as to whether or not the research should be adopted for general use by state highway agencies. To accomplish the research objective, the following tasks are recommended:

1. Identify completed and in-progress research pertaining to bridge scour, streambank erosion/protection and river geomorphology from the last 10 years. The research examined will consist of research that was sponsored by NCHRP as well as non-NCHRP-sponsored research conducted by universities, states, foreign sources, and other entities;
2. Assemble a committee of well-known, prominent researchers with established reputations in bridge scour research, streambank erosion/protection, and river geomorphology;
3. Direct the committee in critically evaluating pertinent research. For each research project evaluated, identify strengths and weaknesses, to include significant findings as well as critical shortcomings;
4. Develop recommendations as to whether or not the research reviewed and evaluated should be adopted for general use by state highway agencies. The recommendations should include the conditions under which the research is applicable and discuss conditions under which the results of the research should not be used. If specific research shows promise, but is not quite ready for general use, recommendations for improvements that are needed in order for the research to be adopted should be made; and
5. Develop recommendations for implementation of the research recommended for general use by state highway agencies.

A significant investment in scour research has been made by the NCHRP, FHWA, state highway agencies, and others in the last 10 years. It is difficult for state highway agencies to determine without assistance whether or not research results are ready for general use by practitioners. Research is needed to define the conditions under which research results may or may not be applicable.

◆ **Project 25-28**

***Assessing Barotrauma Impacts from Aquatic Pile-Driving on Sensitive Fish Species***

Research Field: Transportation Planning  
Source: California  
Allocation: \$450,000  
NCHRP Staff: Christopher J. Hedges

Transportation agencies across the nation are faced with the challenge of meeting the public's increasing demand for efficient transportation systems while reducing the environmental impacts associated with transportation projects. Bridges, ferry terminals, and other structures commonly have driven-pile foundations. Pile-driving is one of the noisiest construction operations. In addition to sound waves produced in the air and vibrations in the soil, pile-driving may produce significant underwater sound. Aquatic pile-driving generates hydroacoustic pressure impulses (noise levels) that can cause effects to fish ranging from altered behavior, through hearing loss and tissue injuries, to immediate mortality. The degree to which an individual fish exposed to sound will be affected is dependent in part on the species, size, the physical condition of the fish, and the duration of the fish's exposure to the noise. State DOTs, harbor districts and others must be able to reasonably predict impact levels that will occur during a pile-driving project to devise appropriate avoidance and attenuation measures for compliance with state and federal environmental regulations.

Because of the lack of scientific knowledge, regulatory agencies, such as NOAA Fisheries, are forced to rely on conservative interpretations of anecdotal information to protect listed species. Most of the work relating to noise impacts on fish has been done with explosives. Explosives produce pressure waves with different shapes and intensities and frequencies than pile-driving. This work will develop an important segment of the information necessary to determine appropriate mitigation levels for pile-driving operations.

The objective of this study is to determine by laboratory work and field validation the nature and degree of impacts to fish over the potential range of sound pressure levels that can occur during aquatic pile-driving operations. The specific tasks are as follows: (1) perform laboratory studies to determine the nature and degree of impacts to selected sensitive Atlantic, Pacific and fresh-water fish species over the potential range of sound pressure levels that can occur during aquatic pile-driving operations in fresh and salt water; (2) develop sound pressure guidelines for protecting these fish; (3) validate the guidelines for selected fish species by field testing at pile-driving sites.

To construct and maintain a transportation system that will support the economy of the country, construction work needs to be done in the water. Pile-driving is a common technique that is used on many projects. To properly protect sensitive fish, it is necessary to be able assess the impacts of underwater pile-driving upon them and to deploy economical effective measures to mitigate those impacts. Fish kills from pile driving have been noted on both coasts and regulatory agencies have imposed standards in both fresh and salt water. Bridge construction projects on the West Coast have been delayed and expensive mitigation requirements have been imposed. The scientific knowledge in this area is limited and needs to be extended. The species in need of protection include such economically important fish as salmon and herring. This research project will develop and validate sound pressure guidelines that are scientifically based and can be used to help determine appropriate mitigation levels. The results of this research will help state DOTs construct projects in aquatic habitat while maintaining the populations of important sensitive fish and meeting the requirements of the Endangered Species Act. The work will be applicable in coastal states and states with major rivers.



## CONTINGENT ON THE AVAILABILITY OF FUNDS

### ♦ Problem No. 2005-B-17

#### *Truck Noise Source Mapping*

Research Field: Transportation Planning  
Source: California  
Allocation: \$500,000  
NCHRP Staff: Christopher J. Hedges

Heavy trucks are major contributors to overall traffic noise levels, and transportation agencies must better understand the precise location and levels of the four principal noise sources (i.e., exhaust, mechanical, tire/pavement, and aerodynamic) on heavy vehicles in order to more successfully mitigate traffic noise impacts.

At more than \$1,300,000 per mile, sound walls are the only approved FHWA solution for addressing traffic noise impacts. The public is demanding other alternatives and quieter pavement surfaces may be part of the solution. Tire/pavement noise from 18-wheeled commercial trucks is believed to be a principal component of overall traffic noise. This study would directly support the recent FHWA Quiet Pavement Pilot Project that is currently underway in both California and Arizona. Data from this project would also yield information that would greatly enhance computer analysis of traffic noise impacts (both California and FHWA noise models) that are a part of many project environmental impact reports. Using the acoustical beamforming technique to collect data, the final product would be a technical report complete with text, data, and figures that accurately identifies, quantifies, and locates the four primary vehicle noise sources on a typical 18-wheeled commercial truck operating in a typical freeway environment. Information from this report would guide decisions made at both a management level and a project design level. If funding and time permits, a wider range of vehicles will be examined.

This work would greatly support states' ongoing efforts to assist the FHWA in the validation of their national Traffic Noise Model computer simulation programs. FHWA will mandate the use of their TNM model in the near future, and the proposed noise mapping would answer many questions.

The objective of this study is to use a recent technological advancement, beamforming, to visually map and quantify noise sources on an 18-wheel-tractor-trailer vehicle operating at freeway speed. This information would be used to mitigate traffic noise through the design of quieter pavement and/or more effective sound walls. It would also improve the computer simulation required for analyzing project noise impacts.

Traffic noise from proposed transportation projects is a hot topic, and heavy trucks are a major noise generator. The public is demanding better and increased noise mitigation solutions such as sound walls and quieter pavement. Noise mitigation techniques could be improved upon once the noise sources are accurately identified and located by the beamforming method.

Information gathered in this research would be used as a reference to guide sound wall and pavement design and improve computer noise modeling.

◆ **Problem No. 2005-C-07**

***Development of a Precast Bent Cap System for Seismic Regions***

Research Field: Design  
Source: AASHTO Highway Subcommittee on Bridges & Structures  
Allocation: \$600,000  
NCHRP Staff: David B. Beal

Precast bent caps are of increasing utility in highway construction. Precasting moves concrete forming, pouring, and curing operations out of the work zone, making bridge construction safer and more environmentally friendly while removing bent cap construction from the critical path. Precasting also improves quality and durability because the work is performed in a more controlled environment. The benefits of precast bent caps support the highway construction philosophy of “get in, get out, stay out.”

Successful use of precast bent caps hinges on proper design, constructability, and performance of the cap-to-column connection. Early uses of precast bent caps were limited to applications where minimal moment and shear transfer were required at connections. Under Texas DOT research project 1748, “Development of a Precast Bent Cap System,” researchers established behavior and developed design guidelines for precast bent cap connections with relatively low moment demand. Longitudinal seismic response of precast spliced-girder bridges has been studied at the University of California at San Diego. However, behavior of precast bent cap connections under seismic loading has not been studied to date.

In seismic regions, provisions must normally be made to transfer greater forces through connections and to ensure girder continuity in the longitudinal direction. For example, the California Department of Transportation recently used precast bent caps for the San Mateo-Hayward bay crossing, which required an additional pour over the precast bent caps for girder continuity. A California State University - Sacramento pilot study for a precast bent cap system in seismic regions examined pullout behavior for bars subjected to tension cyclic loading in a grouted duct connection. The test program indicated only minor bond degradation and slip for epoxy-coated bars embedded 16 bar diameters. Results also provided a basis to establish design and test parameters for beam-column connection specimens for further research. The University of California - San Diego has studied cyclic loading of precast pile to cast-in-place pile cap connections that may provide additional insight on expected behavior.

Research is needed to examine the constructability of precast connections, connection behavior (including the effect of joint reinforcement and other detailing requirements), and girder continuity. Guidelines for design, detailing, and construction must be developed so that precast bent cap technology can be utilized in much of the United States where seismic loading is a design issue.

The objective is to develop a design methodology, connection details, and construction specifications for precast bent cap connections under seismic loading.

The need to move work out of the work zone to improve safety and minimize traffic disruptions is urgent. Precast bent caps have demonstrated their capability of facilitating such movement of work and this research is needed to extend the use of precast bent caps to the many seismic areas in the United States. Research will support the increased attention to design in seismic areas supported by AASHTO.

The design guidelines, constructability study, recommended details, and guide specification development under this study will facilitate implementation. With these deliverables, engineers will be able to implement the results of this study immediately.

◆ **Problem No. 2005-D-07**

***Performance and Quality Control of Corrugated Polyethylene Pipe Manufactured from Recycled Polyethylene Material***

Research Field: Materials and Construction  
Source: AASHTO Highway Subcommittee on Materials  
Allocation: \$250,000  
NCHRP Staff: Edward T. Harrigan

The corrugated polyethylene drainage pipe market is quite large (approximately 1 billion pounds of polyethylene per year in the United States). Millions of pounds of recyclable High Density Polyethylene (HDPE) are generated on an annual basis. Industry-funded research has demonstrated the feasibility of blending recycled with virgin resin to manufacture corrugated HDPE pipe. The general hypothesis is that good quality pipe can be manufactured from blends using recycled resin, if critical resin properties are balanced. Environmental stress crack resistance (ESCR) is one critical property for determining pipe durability. Thermal stability of the blend must also be maintained at the current levels. Since HDPE is a non-renewable resource, it seems prudent to explore the feasibility of utilizing recyclable HDPE material for pipe. However, the use of recycled resin is not currently allowed by AASHTO.

This research needs statement outlines the overall objective to determine the maximum allowable polyolefin and other contaminant levels without adversely affecting long-term service life. Additionally this research is needed to validate a postproduction test performed on finished pipe for recycled materials. This postproduction test should provide assurance of long-term stress crack resistance at levels currently required for pipe made from virgin product, which is currently specified by AASHTO M294. The research must determine if a recycled blend can meet the current resin property requirements specified in the AASHTO Materials Specifications as defined in ASTM D3350.

Since physical properties of recycled material may change, an evaluation of the adequacy of the existing design method and construction standard must be performed to ensure successful usage of corrugated recycled HDPE pipe. This should include evaluation of existing installations where possible. Overall this research will be used to develop a permanent standard for AASHTO.

The objectives of this research are to (1) supply AASHTO with technical information necessary to develop a permanent standard and evaluate the applicability of existing design and to determine the structural and long-term capability of corrugated polyethylene pipe manufactured from recycled resins in highway drainage pipe applications, and (2) determine postproduction testing that will verify the slow crack resistance capacity of the finished product.

The following tasks are anticipated to accomplish these objectives: (1) survey literature and existing recycled pipe installations to quantify performance relative to existing recycled HDPE material standards; (2) define clearly the limits on post-industrial recycled (PIR) and post-consumer recycled (PCR) HDPE permitted in these blends; (3) define the quality control measures needed to ensure that recycled materials meet the required standards to provide long-term performance, correlated with field performance; (4) conduct appropriate research to develop test methods for the final extruded pipe, which contains PIR or PCR materials, to ensure long-term performance, including effects of secondary loads encountered in buried applications; (5) validate results from these test methods, conducted on extruded pipe, using mathematical models based on accepted industry standards; (6) determine maximum allowable contaminate levels without adversely affecting long-term service life or stress crack resistance; (7) determine the effects on properties of additional heat history and grinding on the resins; (8) survey new and existing production and installations to determine recycled pipe performance capability relative to virgin pipe material performance; (9) evaluate existing design methods (LRFD Section 12) to determine appropriateness for recycled material and recommend modification if necessary; (10) define quality control/quality assurance testing required to ensure that recycled material blends can meet the design requirements in LRFD Section 12; (11) evaluate existing construction standards (AASHTO Section 30) to determine appropriateness for recycled material and recommend modifications if necessary; (12) recommend the di-

ameter range and the applications where pipe made from recycled material blends may be used effectively and safely; and (13) prepare a final report presenting (a) the results of the comprehensive literature search, (b) a summary of test results on extruded pipe using appropriate test methods (industry standard or developed in the protocol), (c) validation of projected life forecasts using accepted industry mathematical models, (d) recommendation for a QC test on PIR or PCR materials, (e) recommendation for a QC test on extruded pipe that is correlated with the product life forecast testing, and (f) draft standards in AASHTO format that can be presented to appropriate committees for inclusion in AASHTO publications.

◆ **Problem No. 2005-D-39**

***Measuring Smoothness in Pedestrian Pavement Surfaces***

Research Field: Materials and Construction  
Source: Federal Highway Administration  
Allocation: \$75,000  
NCHRP Staff: Amir N. Hanna

Although there are smoothness standards (e.g., the International Roughness Index) for roadway surfaces used by vehicles, there is no smoothness standard for pedestrian surfaces. Current pavement measuring devices cannot sample at the scale needed to evaluate the rollability of pedestrian surfaces for people who use wheelchairs.

There is a need to adapt or modify walking profilers used to evaluate the smoothness of roadway paving for use in assessing sidewalk smoothness for pedestrians who use wheelchairs. Pavements with known contraindications (e.g., split face granite blocks, pavers with chamfered edges, large-sieve exposed aggregates, wood deckings, and similar surfaces) could be used to establish threshold values without requiring human subject testing.

Current accessibility guidelines under the Americans with Disabilities Act (ADA) and other statutes require walkways to be stable, firm, and slip resistant. ADA limits on abrupt changes in level (1/4 inch) can eliminate the most inappropriate surface choices, but designers continue to select materials and installation details that result in painful and uncomfortable vibration for wheelchair users because there are no specific standards to consult. An easily tested measure of rollability could be used by manufacturers to rate their products and by designers to ensure that sidewalks and other pedestrian routes meet accessibility requirements.

◆ **Problem No. 2005-G-11**

***Regional and National Default Values for Highway Capacity Calculations***

Research Field: Traffic  
Source: Florida, Wisconsin  
Allocation: \$400,000  
NCHRP Staff: B. Ray Derr

The *Year 2000 Highway Capacity Manual (HCM 2000)* is the most extensively referenced document on highway capacity and level-of-service computations in the United States. While the focus of the *HCM 2000* is on providing state-of-the-art simple operational methodologies for practitioners, the *HCM 2000* is at least equally used in planning and preliminary engineering applications. For example, metropolitan planning organizations (MPOs), state departments of transportation (DOTs) and the Federal Highway Administration (FHWA) all to various extents use the HCM for planning applications. Planning and preliminary engineering applications of the HCM make extensive use of default values for the numerous inputs in the *HCM 2000* procedures.

The *HCM 2000* contains over a dozen separate analysis procedures for freeways, rural highways, urban streets, intersections, transit service, bicycle facilities, and pedestrian facilities. Each of these procedures requires a wide range of facility-specific input data to complete the analyses. To assist engineers and planners in applying the HCM procedures, recommended default values are provided in the *HCM 2000* for many of the more difficult-to-obtain required data items. The committee responsible for developing the HCM has up to now had little direct access to field data to indicate what are and are not appropriate default values for critical data items in the *HCM 2000*. The committee has consequently had to rely upon the general knowledge and experience of its members in determining reasonable default values.

The objective of this project is to determine maximum, minimum, and mean values for all significant *HCM 2000* default values for a variety of locations in the United States, and combine them into regional values as appropriate. National default values would also be determined. From these default values, service volume tables would be developed for highway facilities (i.e., all classes of freeways, generally uninterrupted flow highways, and arterials) and applicable highway segments (e.g., uninterrupted flow two-lane segments, basic freeway segments). The intent would be to make these default values and service volumes available to each state DOT and to the HCM oversight committee for consideration for the next edition of the HCM.

The tasks necessary to accomplish this objective include (1) identifying key *HCM 2000* input values and categorizing them based on whether planners do or do not typically have field data; (2) for critical input values, collecting and assembling field data by facility type and region of the country; (3) performing statistical analyses (factor analysis, cluster analysis) to identify the regional, area-type, and facility-type factors that influence the values of the key input variables (The analysis would then use cluster analysis to identify the appropriate segregation of values by region of the United States); and (4) preparation of a report documenting analysis and recommending default values and ranges for key input variables for the *HCM 2000* capacity and level-of-service analysis procedures, with these values categorized by region or other factors as determined in Task 3. The report should also include national/regional generalized maximum service volume tables for applicable highway facilities and segments.

◆ **Problem No. 2005-G-29**

***Freeway Bottleneck Identification, Analysis, and Removal***

Research Field: Traffic  
Source: Nevada  
Allocation: \$600,000  
NCHRP Staff: B. Ray Derr

The presence of bottlenecks on freeways presents a significant challenge that transportation professionals must face when analyzing the operation of a freeway facility, various operational strategies, or different geometric or roadway improvement alternatives. A bottleneck can be described as a specific section of roadway where traffic demand exceeds capacity and becomes oversaturated, which results in a significant worsening of traffic flow conditions. Bottlenecks can occur for many reasons, some of which include high volumes of entering and merging traffic, lane drops between ramps or at off ramps, weaving sections with high volumes of entering and exiting traffic, narrow lanes, horizontal or vertical curves in the roadway alignment restricting sight distance and travel speed, and long upgrades.

It is recognized that there are several concerns related to the elimination of bottlenecks on freeway systems. One concern is the significant design and construction costs related to treating bottlenecks through major construction projects. It is the intent of this project to identify effective low-cost approaches to bottleneck elimination or mitigation, such as ramp metering; re-striping to add a traffic lane; utilization of shoulder space for all traffic, High-Occupancy Vehicles (HOV), or transit during peak hours; and minor re-construction.

Another concern is the relative benefit some bottlenecks may provide when considering system performance. In some cases, when bottlenecks are eliminated or mitigated, the traffic congestion may move downstream to another location, and cause new problems, sometimes offsetting the traffic congestion impacts of the original bottleneck. It is for this reason that system analysis is essential.

The objective of this project is to identify current practices related to bottleneck identification and removal and to develop a technical reference that provides direction, guidance, and recommended practices related to bottleneck identification, analysis, and elimination or mitigation. The primary audience for this document are those individuals who are responsible for managing and operating freeways. It is not intended to serve as a detailed technical reference or design guide.

It is expected that the research will include the following tasks: (1) conduct of a review and critique of previous research efforts to identify freeway bottlenecks and mitigating actions (The product of this effort will be a synthesis report of current practice by operating and planning agencies); (2) review and critique of current freeway management programs and procedures to systematically identify freeway bottlenecks, analyze system performance, and identify cost-effective mitigating actions to optimize freeway system performance (This effort will include interviews with four to six agencies that have demonstrated exemplary practices in addressing the identification and elimination or mitigation of bottlenecks); (3) identification of the data required to identify freeway bottlenecks and their causes and overall freeway system performance; (4) development of a technical reference that will incorporate and summarize the results of Tasks 1, 2 and 3 (This reference document will address the following key topics related to freeway system operational and performance analysis, bottleneck identification, elimination, or mitigation; overview of freeway bottlenecks and causes; potential solutions for elimination or mitigation; analysis procedures--methodology, tools, techniques, data required and level of effort; opportunities for bottleneck removal through roadway improvement alternatives, operational and control strategies; regional and agency initiatives to systematically improve or mitigate impacts of freeway bottlenecks; and case study summaries of examples to highlight successful practices); and (5) validation of the technical reference as the synthesis, outline, and initial and final drafts are developed with selected agencies interviewed as well as others that were not.